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IT Women Mentoring Program 2024-2025

Signal-to-Noise Ratio Forecasting In Mobile Telephony By Data-Driven Modeling

Abstract

The present study employs Empirical Dynamic Modeling (EDM), specifically Simplex projections, to forecast time series of the signal-to-noise ratio (SNR) in mobile phone systems. This approach is complemented by statistical correlation analyses, and the predictions were analyzed using Mean Absolute Error (MAE).

This work was developed using real mobile phone network data from Queen's University's Telecommunications Research Laboratory, and is publicly available as "4G LTE User Equipment Measurements along the 502 Kingston Transit Bus Route" [1].

The correlation coefficient results, indicate that the received signal reference power (RSRP) and the total signal strength (LTERSSI), are factors that greatly influence the SNR. Secondary factors, such as reference signal received quality (RSRQ), vehicle speed, altitude, download rates (DL), and upload rates (UL), showed influences of lesser magnitude, but still statistically relevant.

Simplex projections demonstrated higher performance for a time step ahead. A horizon of five time steps is the limit for good predictions; beyond that, it deteriorates significantly.

Introduction: background, description and results

In telecommunications network research, predicting specific quantities of interest is of crucial importance, as mobile communications have been marked by a growing demand for quality of service and spectral efficiency in recent decades.

SNR, defined as the ratio between signal power and noise power, has emerged as one of the most critical indicators for evaluating the performance of mobile communication systems.

The current landscape of signal quality research is characterized by a transition from analytical approaches to data-driven methodologies.

In this context, Empirical Dynamic Modeling (EDM) represents a promising frontier, offering an approach that does not rely on predefined equations but reconstructs the dynamics of the system from its own time series.

Methodology

The data used covers a range of wireless network parameters associated with 4G LTE, as recorded by two Android mobile devices (Samsung Galaxy S9 and Samsung Galaxy S10e) during 30 bus trips at three different times (9 a.m., 12 p.m., and 6 p.m.), collected along the route of the Kingston Transit Express Bus 502 in Kingston, Ontario, Canada.

The main variables in the dataset are: signal-to-noise ratio (SNR), reference signal received power (RSRP), reference signal received quality (RSRQ), received signal strength indicator in LTE (Long-Term Evolution) networks (LTERSSI), user/device speed, downlink ratio (DL), uplink ratio (UL) and altitude. Figure 1 shows the dynamics of some of these variables over time.

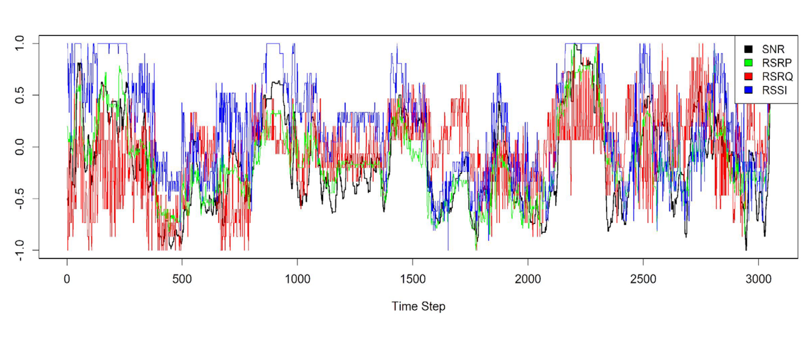

Figure 1 – Signs of the database variables. Dataset: S9-9am-20191127

The data were also analyzed by calculating correlation coefficients (Pearson, Kendall, and Spearman) between the variables. This approach allowed to examine the linear and nonlinear perspectives of the interactions between the variables, with results with a p-value lower than 0.05 being considered relevant.

Subsequently, Empirical Dynamic Modeling (EDM) was implemented, a data-based modeling methodology based on Takens' Theorem [2]. EDM is based on the reconstruction of attractor manifolds from time series data and is mainly applied to time series forecasting and studies on causal inference [3]. The practical implementation was performed using the "rEDM" package in the R language.

Among the various EDM methods, the one implemented was Simplex Projection [4], which works by reconstructing the state space of a system and predicts the next value as a weighted average of the future behavior of the nearest neighboring points. The projections were then analyzed using the Mean Absolute Error (MAE). They were also made in the range of 2000 to 3000 seconds, as shown in Figure 2, and three forecast horizons were applied: TP=1, TP=5, and TP=10.

Figures, data, and main results

Statistical correlation analysis showed that the signal-to-noise ratio (SNR) is mainly determined by the RSRP and the LTERSSI, with the RSRQ also being relevant, but to a lesser extent than RSRP and LTERSSI. An increase in these metrics resulted in higher DL and UL rates. Secondary factors such as user speed and altitude were shown to have a smaller impact, negative and positive, respectively.

All correlations were statistically significant ($p<0.001$), confirming the robustness of the findings across different analysis methods. The overall analysis pointed to RSRP and LTERSSI as key determinants of signal quality in any scenario considered. Comparing devices, the Galaxy S10e maintained slightly higher correlations for RSRQ and was less sensitive to speed than the Galaxy S9.

The application of EDM modeling with Simplex Projection showed promising results for short-term signal quality prediction. The model achieved excellent performance for one time step ahead, with a Pearson correlation of approximately 0.98 between predicted and observed values and a Mean Absolute Error (MAE) of 0.045.

The optimal embedding dimension of 1 indicates that the system has low dynamic complexity, allowing for predictions with low computational cost. The study also identified a five-step-ahead prediction horizon as the limit beyond which the prediction deteriorates significantly. Figures 2 and 3 show the behavior of the predictions for the Galaxy S9 and for the Galaxy S10e, respectively.

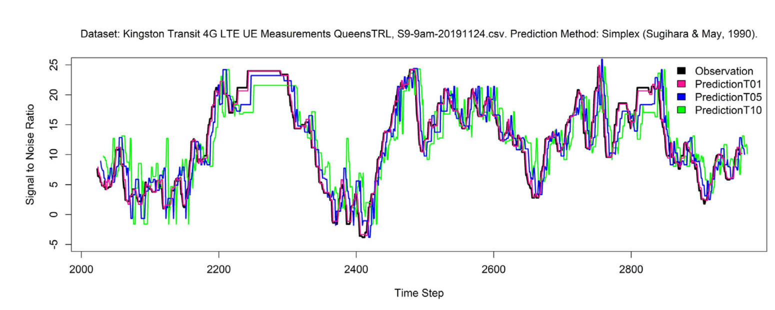

Figure 2 – Simplex projection of SNR over three time horizons (TP = 1, TP = 5, and TP = 10). Dataset: S9-9am-20191124

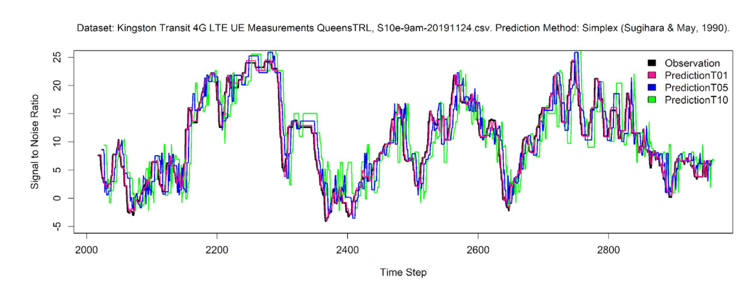

Figure 3 – Simplex projection of SNR over three time horizons (TP = 1, TP = 5, and TP = 10). Dataset: S10e-9am-20191124

Technical relevance

The topic of signal-to-noise ratio (SNR) prediction in mobile phone networks, addressed in this paper, is directly aligned with the traffic engineering and interconnection line of the thematic portfolio of the IT Women program, which prioritizes the development of new methodologies, tools, and solutions for monitoring, measuring, modeling, and optimizing network performance, focusing on aspects such as quality of service (QoS), traffic management, and operational efficiency. Thus, the study is relevant for the advancement of technical knowledge and has potential application for network managers in decision-making to make adjustments of network parameters, to mitigate interference, and to expand planning. Therefore, the predictive tools and models studied in this work can be integrated into traffic monitoring and management systems.

Conclusions, challenges and opportunities

This study demonstrated the feasibility and effectiveness of Empirical Dynamic Modeling (EDM) for predicting signal quality in mobile networks. Statistical analysis confirmed RSRP and LTERSSI as key determinants of signal quality, and the subsequent Simplex Projection achieved excellent performance in short-term predictions, with a correlation of 0.98 between predicted and observed values. The low dynamic complexity of the system, along with the identification of a reliability limit of a five-step time horizon, establish this approach as a computationally efficient and promising tool for network optimization. The next steps will be based on Convergent Cross Mapping (CCM) EDM, which proposes a multivariate scenario, aiming to optimize the current model.

References

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Professional profile

PIBIC-CNPq scholarship recipient and Telecommunications Engineering student at FT-UNICAMP, Brazil. Researches SNR prediction in 4G LTE networks with Empirical Dynamic Modeling, using real data and R application, supporting QoS decisions. Mentored by IT Women/LACNIC; finalist in calculation tournaments, international presentation.

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